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THE VARIATION OF MILK SECRETION WITH AGE IN JERSEY CATTLE.

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BULLETIN 286

THE VARIATION OF MILK SECRETION WITH AGE IN JERSEY CATTLE.*

John W. Gowen.

SUMMARY

The yield of milk changes definitely with age. The change is a logarithmic change not as commonly supposed a linear change.

The variation of milk yield from cow to cow also changes definitely with age. This change is described by a parabolic function.

The curve for growth is logarithmic. The similarity of the two curves suggests the increase in milk production with age could be accounted for by growth of the mammary gland.

A large body of exact scientific data on milk production has been accumulated since the time of the establishment of the Advanced Registry system of the Holstein-Friesian Association of America and its later adoption by the associations of the other breeds of dairy cattle. These completed records are unique in several ways, chief among which is the fact that the records of the cows included among them must meet a certain standard of performance. This standard for entry has the effect of cutting out certain records of cows of the given breed. Thus the Jersey Registry of Merit say that, "if the test is commenced the day the cow is two years old, or previous to that day, she must produce, within one year from the date the test begins, 250.5 pounds butter-fat. For each day the cow is over two years at the beginning of her year's test, the amount of butter-fat she must produce in the year is fixed by adding 0.1 (one-tenth) of

*This paper is an abstract of a longer paper on "Studies in Milk Secretion V. On the Variations and Correlations of Milk Secretion with Age in Jersey Cattle by the same author published in Genetics, March 1920. All literature citations should be made to this complete paper.

a pound for each such day to the 250.5 pounds required when two years old. This ratio of increase applies until the cow is five years old at the beginning of her test, when the required amount will have reached 360 pounds, which will be the amount of butter-fat required of all cows five years old or over. These standards are based upon one complete year's record from the time of beginning, regardless of any time which may be lost by being dry or calving during the period." Three facts are obviously true of the Jersey Registry of Merit cows as compared with a true sample taken at random of the milking cows of the Jersey breed; (1) the cows making up the Registry of Merit are a selected sample; (2) the scale of the selection is linear having its lower limit 250.5 pounds of butter-fat production at 2 years and its upper limit 360 pounds at 5 years and over; (3) this requirement means that for each day of age at test the frequency distributions of years production are cut off perpendicularly at the requirement and only those animals making greater yields than this are allowed to be entered into the Registry of Merit. The data taken from this Registry of Merit are not the true data for the Jersey breed and conclusions based on it cannot be considered as applying to the breed as a whole or to the general problems of milk secretion.

To supply this need of exact data on the Jersey breed as a whole the Maine Agricultural Experiment Station has obtained the recorded data of one of the largest pure bred Jersey herds known. The data are exceptional in the following ways: (1) The records extend back to the year 1897 when the herd was organized; (2) the animals are practically all straight island stock; (3) they have been under the oversight and direction of one manager since 1901; (4) exact records are kept of the milk production, butter-fat and butter-fat per cent; (5) many of the individual animals have records for several different lactations. The elimination of variation of the milk production of cows or groups of cows caused by changes in any one or more of these five factors is important for the analysis of the causative mechanism of milk and butter-fat production. It is obvious that these records are free from such variables. They constitute a homogeneous group of data representing the island Jersey under constant conditions of management and climate.

Such an accumulation of exact statistical data on the cows of the Jersey breed for problems of so much interest, both biologically and economically, warrants the application of adequate biometrical methods in their analysis. The necessity of such analysis is now well recognized by most investigators as of the utmost importance to our understanding of the fundamental principles of physiology which underlie the process of milk secretion itself.

The general problems attacked are those of the individual variation between the lactating functions of different dairy cows at a given age. What is the true type of the frequency distributions of milk production? What relation exists between the mean productions of the successive ages in a true random sample of the Jersey breed? An understanding of these and similar questions is necessary to the fuller utilization of the data found in the herd book of the registry association.

The data used for study are all from normal, healthy cows. Two diseases have been present in the herd, tuberculosis and abortion. The tuberculous animals were all eliminated early in the herd's history by the use of the tuberculin test. All records from animals which were proven to be tubercular or which aborted were not used. Records from animals normally healthy but sick during a given lactation were not used. All of the cows have been kept in climatic conditions similar to those of Western Virginia.

A word as to the method of keeping the data and its transfer to this Station. All records are made at the time of milking on the daily milk sheet for the given cow which are kept in the barn. The milking takes place twice a day, the records are for night and morning. The weekly production taken from these sheets is transferred to the herd ledger by a trained bookkeeper. The total production for a given month is found together with the yearly production by adding the weekly totals. All records are recorded to pounds and tenths. The cows are tested bi-monthly by the Babcock test and the percentage of butter-fat is recorded beside its corresponding monthly milk yield. All weighings and readings are recorded immediately after they are made so there is little chance of inaccuracy. From these records the author has extracted 1741 complete 8 months records of healthy cows for milk production. Of these 1741,

1713 have records for the butter-fat percent. The weighed monthly averages of the bi-monthly test have been used to obtain the weighed 8 months average for the 8 months lactation period chosen for study.

VARIATION OF JERSEY MILK PRODUCTION WITH AGE AT COMMENCEMENT OF TEST.

The tabulation of these records in complete eight months records has been done by the author. The chief physical constants of the distributions are presented in table 1 together with their probable errors.

TABLE 1.

Constants of Variation of Milk Production for the Successive Ages at Test in Jersey Milk. (8 Months Lactation Period).

Age at Test	Mean	Standard Deviation	Coefficient of Variation	Skewness
2 years 0 months to 3 years 0 months	4032.9±31.7	818.9±22.4	20.304± .577	
3 years 0 months to 4 years 0 months	4686.5±46.8	1101.5±33.1	23.503± .712	+0.2642±.0548
4 years 0 months to 5 years 0 months	4992.9±46.3	1079.4±33.0	21.619± .684	+0.3532±.0635
5 years 0 months to 6 years 0 months	5281.4±57.0	1262.8±40.3	23.911± .801	+0.3894±.0714
6 years 0 months to 7 years 0 months	5536.5±64.5	1325.3±45.6	23.938± .865	+0.2586±.0628
7 years 0 months to 8 years 0 months	5314.7±64.9	1255.0±45.9	23.613± .907	
8 years 0 months to 9 years 0 months	5226.4±77.9	1302.0±55.1	24.912±1.111	+0.3141±.1173
9 years 0 months to 10 years 0 months	4938.2±95.3	1302.6±67.4	26.377±1.453	
10 years 0 months and above	4838.8±70.3	1077.3±49.7	22.264±1.028	
Total population	4887.6±20.2	1249.7±14.3	25.569± .310	+0.3150±.0222

The mean milk production for the eight months period, for those cows which are between 2 and 3 years of age, is 4032.9 pounds. From this point the milk production rises rapidly at first then more slowly to a maximum at about 7 years. From this maximum the decline in milk production is less rapid toward the higher ages.

The difference between the production of 2 years and 6 months and the maximum is significant as the difference is about 20 times its probable error (1503.6±71.9). The difference between the maximum production and that for the 10 years and above is also significant as the difference is more than 6 times the probable error (697.7±95.40). This rise and fall of milk

production with age has already been shown, by the work of this laboratory, to conform to that group of curves described by a logarithmic function.

The standard deviation varies between 818.9 pounds at the age of 2 to 3 years to 1325.3 pounds at the age of 6 to 7 years. The rise of the standard deviation is more direct than is the rise of the mean curve. From the maximum the curve remains parallel with the base line for some years when it again drops to a lower deviation at the highest age at test. This rise and fall is significant as judged by the probable errors of the difference. The difference of the maximum standard deviation at 6 to 7 years from that at 2 to 3 years is 506.4 pounds of milk where the probable error is 50.8 pounds or the difference is practically 10 times the probable error and the probability that this difference did not come from random sampling is considerably greater than 1,000,000,000 to 1. The difference between the maximum standard deviation and that at 10 years and above is 248.0 pounds and the probable error is 67.5 pounds or 3.68 times the probable error and the probability that this difference did not come from random sampling is 75.7 to 1. From these above facts the conclusion seems justified that milk production varies with age at test in such a way that the absolute amount of the variation in production from one cow to another is least at the early age, increases rapidly to a maximum at about 5 years and 6 months, remains at this maximum for about four years then falls again toward the later ages.

The coefficient of variation for the milk production of the successive ages are all high as compared with those already

TABLE 2.

Comparison Data for Coefficients of Variation of Amount of Secretion.

Organism	Secretion	Coefficient of Variation	Source of Data
Domestic Fowl (Barred Plymouth Rock)	Annual Egg Production	34.21±.37#	Pearl
Cattle British Holstein	Gallons of milk	25.72±.37	Gavin
Cattle Ayrshire	Gallons of milk	24.18±.50*	Vigor
Cattle Jerseys	Pounds of milk	25.56±.31	This paper

#Probable error calculated by author from total given in paper.
*Calculated by the author from the means and standard deviation as given by Mr. Vigor.

known for other similar data. This large size in the coefficients is brought out by table 2.

Of the substance studied annual egg production is the most variable. The coefficient of variation for milk production corresponds remarkably well considering the diversity of the sources from which they are taken. They all go to show that milk production varies around a mean of 25 or is about 9 per cent less variable than egg production. This difference is significant. The mechanism of the secretion of the sum of the egg parts to form the egg is shown to be more variable than that for the secretion of the milk parts to form the milk. Taking this reasoning back to its ultimate source, such a significant difference shows that the secretory cells of the mammary glands work with greater precision than do the cells of the oviduct. Such a difference in the variation of action of the two sets of cells would seem to indicate a greater approach to perfection, in a mechanical sense, in the cells of the udder than is true of the cells of the oviduct.

The skewness of the two sets of data furnish another interesting contrast. The skewness of annual egg production for Barred Plymouth Rock hens is —0.205, whereas the skewness for Jersey milk production is +0.315. Not only is the sign different but the actual amount is different. This cannot be explained on the basis of any selection for high producers that may have taken place as both sets of data are about equally subject to such selection. The data for the successive age groups all goes to show that where the distributions for milk production are skew they are all plus. This lends further strength to the belief that the distribution for the yearly production of the two sets of glands is skew in opposite directions. One thing is common in the two cases, the skewness in each is small in amount. This is of especial importance as it shows the approach to the value where the typical Gaussian curve of error may describe these functions.

This question is of great importance in considering the milking records of advanced registry animals where it is necessary to form an opinion of the capacities of a breed from the milking abilities of a selected sample where the selection is not at random but removes those cows producing under a certain amount.

This feature of the problem is seen in the work of Reitz (1909) on the inheritance of butter-fat production in Holstein Friesian cattle. The data for this problem came from the advanced registry of Holstein Friesian cattle. Since as a requirement to entry in this registry the cows must produce more than a certain amount of butter-fat, the correlation from such data measuring the strength of inheritance are subject to a double selection. Rietz in correcting for this selection uses the method devised by Pearson to determine the whole of a normal curve when a portion of it is known. The accuracy of the corrections depends then on the curves for milk production and for butter-fat percentage being normal.

When the frequency curves for milk production of these data are analyzed by the method of moments for their type equations it is found that five of the curves belong to the type I group, four to the type II group and one to the type IV group. Nine of the ten curves are of limited range. These limits are of interest as they indicate the maximum and minimum productions to be expected from this group of cows. The limits of the range of the type II curves are on the whole somewhat underestimated. The type I curves more nearly record the facts of the case save in the curve for the total population where the range is considerably overestimated due to the slow approach to zero of the ends of the distribution. For such a distribution it must be remembered that the frequency becomes very small as the ordinary limits of the observation are passed.

On the whole the fit of the curves is excellent comparing favorably with that of any similar data. It is evident therefore that the skew frequency curves describe these data well. The question now arises in view of the difficulty of correcting for this skewness in correlation studies on the heredity of milk production, if the fit of the Gaussian curves is sufficiently good to allow of the use of this method.

When these curves are used it is found that the normal curves do not describe milk production at the different ages or for the total curve as well as do the proper type curves. The difference in the fit of the type curves over the normal curve comes especially in the description of the tails and the skewness of these distributions. The fit of the normal curves is not bad, however, and in all probability no serious error would be made

in the use of them for the determination of the corrections to be applied to the correlations from double-selected data as was done by Rietz.

THE CORRELATION OF JERSEY 8 MONTHS MILK PRODUCTION WITH THE AGE AT TEST.

Common knowledge among dairymen is that milk production and age at the commencement of the lactation are correlated in such a way that advancing age means increased production. The opinion is general that this increase is a linear one.

TABLE 3.

Correlation Surface for Pounds of Milk and Age at Test for Jersey Cattle.

(Lactation Period 8 Months).

	1000– 1500	1500– 2000	2000– 2500	2500– 3000	3000– 3500	3500– 4000	4000– 4500	4500– 5000	5000– 5500	5500– 6000	6000– 6500	6500– 7000	7000– 7500	7500– 8000	8000– 8500	8500– 9000	9000– 9500	9500–10000	10000–10500	10500–11000	Total
1:6– 2:0				5	15	10	2	2													34
2:0– 2:6	1		4	19	54	51	56	42	19	7	2										255
2:6– 3:0			1	4	6	7	11	12	4	4											49
3:0– 3:6				4	21	22	33	30	20	13	8	3	2								156
3:6– 4:0			3	3	6	9	14	19	16	8	7	3	5	2	1						96
4:0– 4:6				2	8	15	31	24	25	15	7	8	1	2		1					139
4:6– 5:0					7	11	13	20	24	13	8	3	5	3	1						108
5:0– 5:6					7	13	16	14	23	10	5	7	9	2	1	1					108
5:6– 6:0					5	13	12	19	17	15	14	9	4	3	3				1		115
6:0– 6:6				2	2	10	14	8	14	12	12	5	6	3	3			1			92
6:6– 7:0					4	6	9	15	15	12	16	8	7	4	1		2		1		100
7:0– 7:6			2	1	4	5	16	11	19	7	6	5	5	2							83
7:6– 8:0					3	11	8	9	9	14	14	9	5	1	3	1					87
8:0– 8:6				1	7	7	7	10	15	8	7	4	2	1	1				1		71
8:6– 9:0					2	8	8	3	12	7	6	5	3	1				1			56
9:0– 9:6			1	3	4	3	7	9	7		3	5	1								43
9:6–10:0			1	3	1	3	4	6	8	5	5	3	1	1	1						42
10:0–10:6					1	1	3	9	6	1	1	4									26
10:6–11:0			1		3	3	2	2	4	3	3	1	1	1							24
11:0–11:6				1	3	2	6	5	3	4	1		1								26
11:6–12:0							2	1	1		1										5
12:0–12:6				1	3			2	1	2											9
12:6–13:0						1	2	1	2	1											7
13:0–13:6				1		1	1		1	1											5
13:6–14:0							1				1										2
14:0–14:6								1	1												2
14:6–15:0																					
15:0–15:6							1														1
15:6–16:0																					
Total	1		13	50	166	212	279	274	266	162	127	82	58	26	15	3	2	2	3		1741

This opinion has been shown to be erroneous by previous work of this laboratory on the statistics of the 7 day records of American Jersey cattle found in "Jersey sires with their tested daughters," published by the American Jersey Cattle Club. In this work seven day milk production is shown to be a logarithmic curve and not a straight line.

It remains to be shown that this same type of curve describes a true random sample of the Jersey breed for a longer milk period. Data of this sort are important for several reasons chief among which, both practically and theoretically, is the necessity of having suitable correction factors for age to allow comparison of milk records at different periods in the lives of different cows. Toward the solution of this problem the following facts are necessary; what correlation exists between age and milk production; is this correlation sufficient so that it must be taken into account in considering records of different cows at different ages; what is the equation of the regression line between these two variables. Table 3 furnishes the data necessary for this study.

The correlation and its accompanying constants for these two variables are shown in Table 4.

TABLE 4.

Constants Measuring the Association between Amount of Eight Months Milk Produced and Age at Test of Jersey Cows.

r	η	$\eta - r$	$\eta^2 - r^2$
0.2596±.0151	0.4283±.0132	0.1689±.0201	0.1161±.0108

This table makes clear several facts concerning the influence of age on milk production. The correlation of +0.2596±.0151 shows that age at test and milk production are significantly correlated variates. Taken in conjunction with the correlation ratio it shows clearly that age of the cow at commencement of test must be considered in comparing the records of different cows if the conclusion from the comparison is to be valid. The value of the correlation ratio +0.4283±.0132 is considerably

higher than the correlation coefficient. This difference is shown to be highly significant by the value of $\eta - r$ $+0.1689 \pm .0201$. It is altogether probable therefore that the regression of age on milk production is a skew regression. This is shown to be a fact by the constant to measure such skewness. $\eta^2 - r^2$ $0.1161 \pm .0108$ is about 11 times its probable error. The regression is therefore known to be skew. Since this is true the correlation ratio is a better measure of the true correlation than is the correlation coefficient. The relation of age at test is then doubly significant in any comparison of the records of two cows. The regression having been shown to be skew it becomes necessary to deal with it separately.

TYPE OF THE REGRESSION OF MILK PRODUCTION ON AGE OF JERSEY CATTLE.

The means for each array of age have been calculated.

From these means the theoretical curve conforming to the general logarithmic type has been calculated by the method of least squares. The equation to this curve is

$$y = 3387.912 - 99.883x - .487x^2 + 2896.219 \; Log \; x$$

where x is taken in six months intervals from an origin at 1 year and 3 months.

The observations at the higher ages vary a good deal as they are based on small numbers. The theoretical curve strikes through them quite accurately when the unevenness of the observed curve is considered. When we calculate the χ^2 by the method of Slutsky we find that 5 observations contribute a sum of 28.80 to the total of 45.41. These observations are at ages 2 years 9 months, 3 years 3 months, 6 years 9 months, 7 years 9 months and 9 years 3 months. If we measure the fit by the total χ^2 45.41 it is poor. Considering the above mentioned five observations in connection with the other observations it is seen that two of them are plus and three are minus quantities. Not only that but they come at places in the curve so that they would practically counteract each other if the first smoothed curve were used as the observational. It seems altogether reasonable

therefore to consider the fit of this curve measured by a χ^2 somewhat more than 17.00 or what would correspond to the P of a very good fit.

The equation of the curve has many practical uses aside from its interest in a scientific sense. By its use the records of cows at different ages may be brought to the same basis for comparison whether it be for milk inheritance studies, analysis of judging experiments or the like. The time of the theoretical maximum of milk production may be easily calculated from it by differentiation. This maximum is shown to be 7 years 2.4 months a figure considerably above the age customarily called mature form. Further the curve shows that the method used in advanced registry work of determining the amount a Jersey cow should produce for the Register of Merit is falacious in that it is a linear method and does not recognize this logarithmic nature of milk production. In a previous paper the average fat per cent of Jersey cows is given as 5.12. Assuming this figure and dividing the pounds of butter-fat by it gives us the average requirement for milk production in one year. Supposing that ¾ of the year's records is made in the first 8 months of lactation (a figure reasonably close to the expected (Pearl 1915) the required production is found to be 3600 pounds at 2 years and 5200 pounds at 5 years.

Causally considered the logarithmic nature of milk production is of a good deal of interest. The work of a number of students of growth, beginning with Minot's notable studies on rabbits have shown that the phenomena of growth is also a logarithmic function of age. This law appears of wide general application as the work of Lewenz and Pearson have shown it holds for growth in children; Donaldson, Hatai and Jackson have shown it is of general application to the growth of certain organs in the white rat and Pearl and Surface have shown it true for ceratophyllum and corn. It seems, therefore, altogether likely that the mammary glands of the cow also follows this rule. Should this prove true the increase of milk production with age seems of much significance in paralleling these growth phenomena. This paralleling of the two functions would, in fact, seem to indicate causal relation between the two in that the increase in milk production may depend chiefly on the increase in actual mass of the mammary gland due to growth of

this organ and not due to any relative increase in the ability of the cells to secrete more milk.

In a Bulletin to follow this, the relation of the milk yield for one lactation in comparison with that of another subsequent lactation will be analyzed for the same data as presented here.